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Control of paralyzed skeletal muscles: A neural prosthesis

C. M. IONESCU and R. M. C. DE KEYSER

Department of Electrical Energy, Systems and Automation, Ghent University, Ghent, Belgium

1. Introduction

One of the most used methods to perform artificial control of muscles is based on functional electrical stimulation (FES), which enables restoration of movement (e.g. arm, knee). FES-based devices use electric current pulses to stimulate and excite the (intact) peripheral nerves. Therapeutic electrical stimulation for paralyzed, or paretic muscles, or damaged ligament in the knee, has proved to be an efficacious rehabilitation tool in clinical trials on humans (Richmond *et al.* 2001).

2. Controller task

Applications for (foot) motor control in patients with a drop-foot, or for hand-grasp control of humans with paralyzed hand muscles, have confirmed the basic theories that natural sensory signals can be used to control paralyzed muscles (Richmond *et al.* 2001). The input to the controller (R) is the error (difference between the desired force and measured resulting force), and the output is the frequency of the stimulus (figure 1). In a classical approach, the tuning of the controller parameters are based on a model of the muscle and a 'manual' tuning which is tedious and also has to be performed for each person.

In the solution proposed, the identification of the controller parameters is done within a direct adaptive control (DIRAC) strategy. Therefore, it is no need for *a priori* specifying a model of the process, thus it functions as an *auto-tuning* method. The justification in using a (self) adaptive controller stands within the fact that the parameters of the muscle are time-varying, especially in cases of rehabilitation (hand-grasp, knee joint, drop-foot, etc.). Even in normal-healthy persons, these parameters changes with exercise, age, (calcium and magnesium) metabolism, etc. Finally, inter-subject variability supports the motivation to use an auto-tuning adaptive controller.

Basically, the DIRAC strategy is based on specifying a reference model (with desired performance) of the closed loop transfer function. By means of an estimation

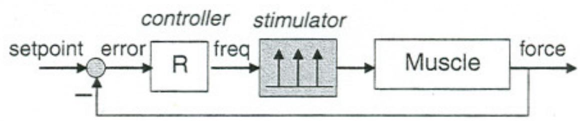

Figure 1. Schematic overview of the closed-loop.

algorithm (e.g. least squares), the controller parameters are estimated such that the closed loop performance fulfils the specifications given in the reference function. This is then a simple and easy-to-implement regulating algorithm which does not need a model of the system and it automatically adapts the controller parameter when changes appear in the system.

3. Results and discussion

In this (simulation) case, the natural sensory signal is captured by an electrode, fed to an amplifier/controller unit and led to the paralyzed muscles. A linear model capturing the properties of a muscle under isometric conditions can be represented by a 2[nd] order transfer function with delay: $M(s) = Ke^{-\tau_d s}/(s+a)(s+b)$.

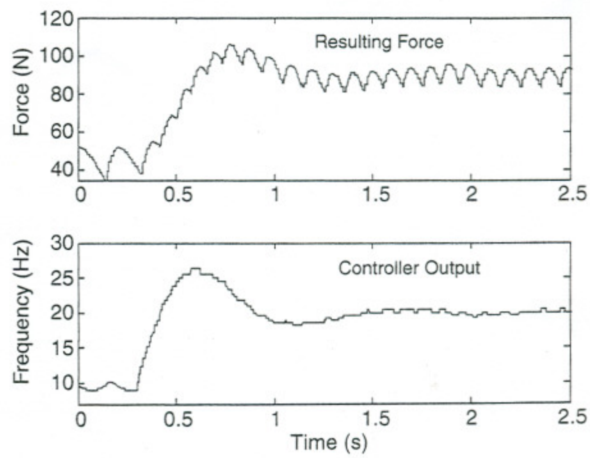

Figure 2. Resulting force (N) and controller output (Hz) for skeletal muscle control for setpoint change.

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The parameters ($K = 450$, $a = 5$, $b = 20$, $\tau_d = 0.005$ s) are a *nominal* set and their value can change from person-to-person. The control performance test consisted in *changing the reference set-point* (= force) from 45 N (10 Hz) to 90 N (18 Hz) as in figure 2.

4. Conclusion

DIRAC strategy has the advantage that it can be implemented on devices and used in rehabilitation without the prerequisite of a muscle/patient model, due to its auto-tuning characteristic. A comparison with classical PID control is provided in (Ionescu and De Keyser 2005). The problem imposed and evaluated here is the presence of the time delay in the closed-loop. DIRAC strategy performed satisfactorily and it is a straightforward strategy that can be easily implemented on-line, on a real-life device (due to its simplicity and discrete nature).

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